An Integrated Evaluation of Geoscientific Data to Bring out Hydrocarbon Entrapment Model of South Nagapattinam Subbasin, Cauvery Basin

Tapas Mitra[1], Jayanita Baral[1], Sukumar Pahari[2], Ashish Ghosh[3],

[1]KDMIPE, ONGC, Dehradun;
[2]Geochemistry Division, KDMIPE, ONGC, Dehradun,
[3]Southern Region, ONGC, Chennai

Summary

Eastern boundary of Indian plate was rifted from Gondwanaland during Albian time. In the south Nagapattinam area of Cauvery Basin, two roughly North – South trending, easterly hading extensional fault systems are identified. Extensional voids thus created were compensated by north-south trending westerly hading accommodation faults. Most of the structures created due to accommodation folding at the up thrown sides of these faults have been probed for hydrocarbon. Late and post Cretaceous tectonics created some east – west trending fault systems.

Synrift sediments of Albian period (Sequence K1) are consisting two major facies. Toes of the footwalls are probably consisting of very immature, poorly sorted slide and slump deposited sandstones. However during the late rift stage chances of getting channel derived better sorted sands are not ruled out. Otherwise the major lithology is pelagic and hemipelagic shales. Like other parts of Cauvery basin in (south) Nagapattinam sub basin also these Albian shales are the only effective source rocks.

An easterly to south-easterly slope was created due to the north-south trending easterly hading normal extensional fault systems. Early syndrift sequences of Turonian and Cenomanian age (Sequence K2) was deposited in this passive margin set up. In the southern part of the stemmed fault systems, the deposition was mainly dominated by short spanning non-Newtonian flow, resulting in poor reservoir facies. Northern spread apart fault systems supported longish Newtonian flow systems, resulting in well sorted submarine fan and channel fill deposits, being an ideal locale for deliberate subtle trap exploration.

End of sequence K2 is a type 1 sequence boundary, triggered by fresh tectonics, resulting in reactivation of many faults in the study area. The next sequence of Coniacian to Lower Campanian age (Sequence K3T) was however deposited in an overall trangressive regime, and thus failed to deposit much of coarser clastics. End of the sequence K3T was a type 2 sequence boundary, triggered by fresh bout of tectonics and further reactivation of few faults. The depositional mechanism was probably stacked channel systems, in shallow marine environments, which reworked earlier sediments. Thus attained peneplanation or near peneplanation was however a short lived one, being disturbed by fresh tectonics at the end of sequence K3R, creating a major unconformity at the end (KTB).

Introduction

Nagapattinam sub basin is producing commercial quantity of hydrocarbons from the sands ranging from Albian to Oligocene. The northern part of the Nagapattinam sub basin has major hydrocarbon producing fields like Kamalapuram, Adiyakkamangalam, Tiruvarur, Kizhavalur and Narimanam. The southern part of subbasin apart from having smaller oil fields like Kovilkallapal and Tulsapattinam also has a hydrocarbon bearing structure: Tirukallar. Some more wells drilled in adjacent structures have indicated presence of gas and fluorescence/cut in the cuttings and cores.

The objective of this study was to identify and analyse the depositional model of Upper Cretaceous, to understand the Petroleum system, and to decipher the Paleotectonic evolution and identification of exploration targets of South Nagapattinam subbasin (Fig. 1).

For regional interpretation, basic sequence stratigraphic techniques were applied. As an outcome four major tectonostratigraphic sequences have been identified within Cretaceous (Table: 1) :

1. K3R: Mid. Campanian to Maestrichtian
2. K3T: Coniacian to Lr Campanian

Table1: Bio-chrono Sequence Chart Of Cauvery Basin

SEQUENCE		BIOZONE	AGE	
T4		N16-N22	UP. MIO TO RECENT	
T3		N4-N15	LR – MID MIO	
T2	T2.5	P22	UP. OLIG	OLIG.
	T2.4	P21	(CHATTIAN)	
	T2.3	P20?		
	T2.2	P19	Lr. OLIG.	
	T2.1	P18	(RUPELIAN)	
T1	T1.5	P15-P17	UP. EOC	EOC.
	T1.4	P10-P14	MID. EOC.	
	T1.3	P6-P9	LR. EOC.	
	T1.2	P3-P5	UP. PAL.	PAL.
	T1.1	P1-P2	LR. PAL	
K3	K3R	G. GANSERRI	UP. MAAS	UP.
		A.		CRET
		MAYAROENSIS	UP. CAMP- LR.	
		G. STUARTI	MAAS	
		G.	MID. CAMP.	
		VENTRICOSA		
	K3T	G. ELEVATA	LR. CAMP.	
		D.	SANT-LR CAMP	
		CONCAVATA		
		D.	CONIACIAN	
		ASYMETRICA		
		M. RENZI		
K2			TUR. – CENOMANIAN	
K1			ALBIAN	LR. CRET
K0			PRE ALBIAN	
BASEMENT			ARCHEAN	

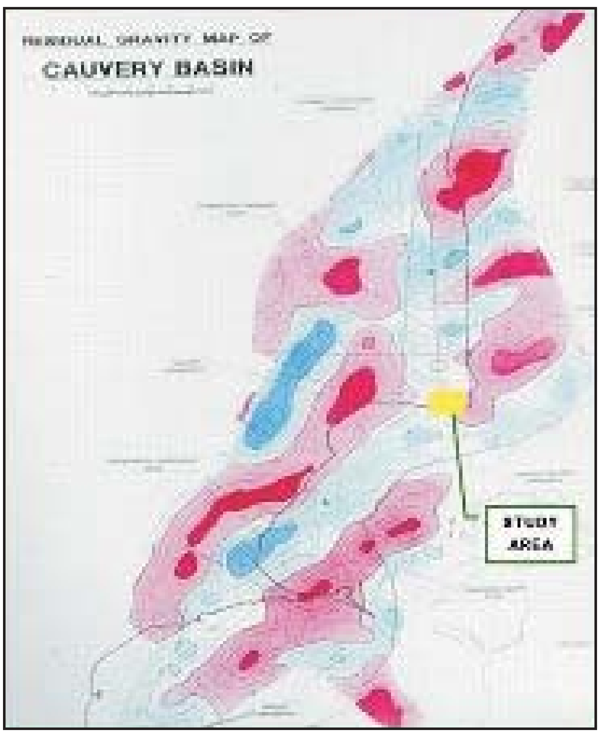


Fig. 1: Residual Gravity map of Cambay basin showing the study area

3. K2: Cenomanian to Turonian
4. K1: Albian

Paleotectonics and depositional history

Eastern boundary of Indian plate was rifted from Gondwanaland during Albian time. This extensional tectonics created roughly North – South trending Easterly hading normal fault systems. In the south Nagapattinam area two such major fault systems could be identified (fig.2). Stemmed at south, the fault systems are spreading apart on the plane towards north. This geometry is in conformity with actual split of the eastern boundary of the Indian plate, which was an anticlockwise rifting. Initiated during sequence K1 period, some of these easterly hading normal extensional faults continued gradually as growth faults during the drifting of the Indian plate. However few of them remained dormant occasionally and underwent periodical reactivation (Fig. 4, 5). Extensional voids thus created were compensated by north-south trending westerly hading accommodation faults. Most of the structures created due to accommodation folding at the up thrown side of these faults have been probed for hydrocarbon (Fig. 2). Late and post Cretaceous tectonics created some east – west trending fault systems.

Sequence K1:

During this synriftal time (fig 10), half grabens form during crustal extension that is accommodated by normal faults, which commonly eases in gradient with depth, caused collapse of the hanging wall and formation of

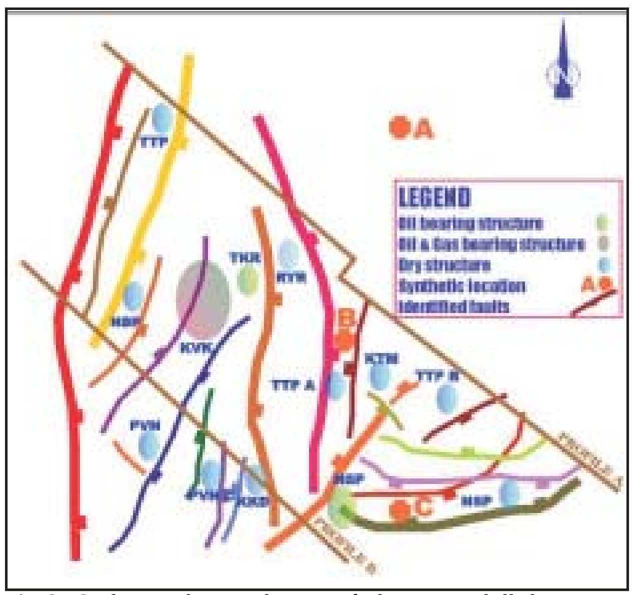


Fig. 2: Study area showing the major fault systems, drilled structures and location of synthetic wells

inclined rollover panels (Hamblin, 1965) (fig.3-6). Purely rigid-block translation of the hanging wall over a normal fault that tends to lower in gradient with depth produces a large void between fault blocks that cannot be supported at depth (fig.6). Collapse of hanging walls into these voids formed inclined fold limbs or "rollovers" above nonplanar faults (Hamblin, 1965); these rollovers have been observed in rift basins worldwide (e.g., Bally, 1983; James, 1984; Nunns, 1991, Xiao and Suppe ,1992).

The geometries of normal faults and associated rollover panels control the size and shape of accommodation spaces in half grabens where sediments can be deposited.(fig.10) Synrift sediments of Albian period (sequence K1) are consisting three major facies. Toes of the footwalls are probably consisting of very immature, poorly sorted slide and slump deposited sandstones deposited during early rift period. However in the study area there are no strategically drilled wells through these sections. Otherwise the major lithologies are pelagic and hemipelagic shales and low energy driven silts and fine sands deposited during the succeeding rift climax period. The deep basinal setup of early rift period also probably received these finer sediments. However during the laterift, first stage of near peneplanation in this part of the subbasin was achieved by the channel derived sands. Like other parts of Cauvery basin in (south) Nagapattinam sub basin also these synriftal Albian shales are the only effective source rocks (Fig. 4, 5).

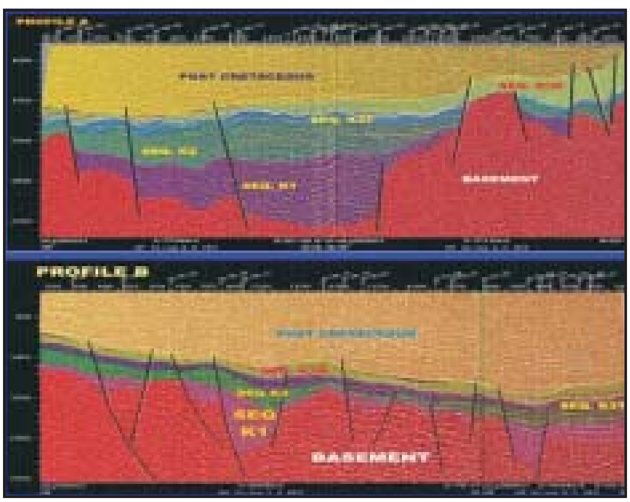


Fig. 3: Profile A & B as depicted in the fig. 2. Note the spread apart fault systems in Profile A at the northern part of the study area supporting longish drainage systems for sequence K2. Profile B on the other hand is at the southern stemmed fault system having restricted depocenters for sequence K2.

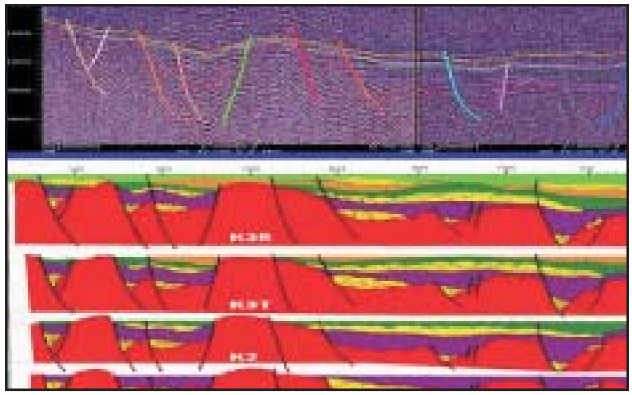


Fig.4: Paleotectonic analysis and predicted coarser clastic depositions

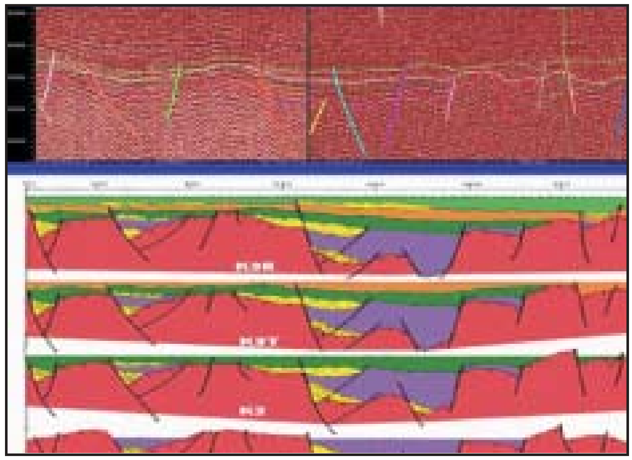


Fig.5: Paleotectonic analysis and predicted coarser clastic depositions along NW-SE trending seismic section

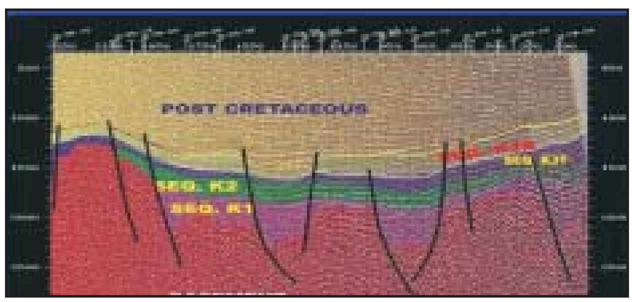


Fig.6: Seismic section showing the interpreted sequences

Sequence K2:

During this period (fig. 10) spanning from Cenomanian to Turonian, easterly to southeasterly slope was created due to the north-south trending easterly hading normal extensional fault systems. The major depocentre thus created towards east and south-east of Kovilkallapal high is abated by the Thiruturaipundi high towards further south-eastern part of the study area. Early syndrift sequence K2 was deposited in this set up (Fig. 3-6).

Deposits of this sequence in the Kovikalappal area show higher content of feldspar and Na_2O compared to Kattimedu, Tulsapattinam and Tagattur area, indicating lower mineralogical maturity (fig. 7). This indicates that in the southern part of the stemmed fault systems, the deposition was mainly dominated by short-spanning non-Newtonian flow resulting in slide and slump derived poorly sorted coarser clastics admixed with huge amount of clay matrix. The core study of a Kovilkallapal well indicates slumping (fig.8). The dominance of kaolinite clay towards Kovilkallapal area indicates meteoric water diagenesis. The presence of more algal fragments along with sediments in Kattimedu & Tulsapattinam area (fig.9) indicate submarine environment of sedimentation. The geochemical data showing low K_2O value towards Kattimedu-A (fig. 7) indicates better mineralogical maturity in this area. This phenomenon proves that northern spread apart fault systems supported longish Newtonian flow systems resulting in well-sorted submarine fan and channel fill reservoir facies (Fig. 2).

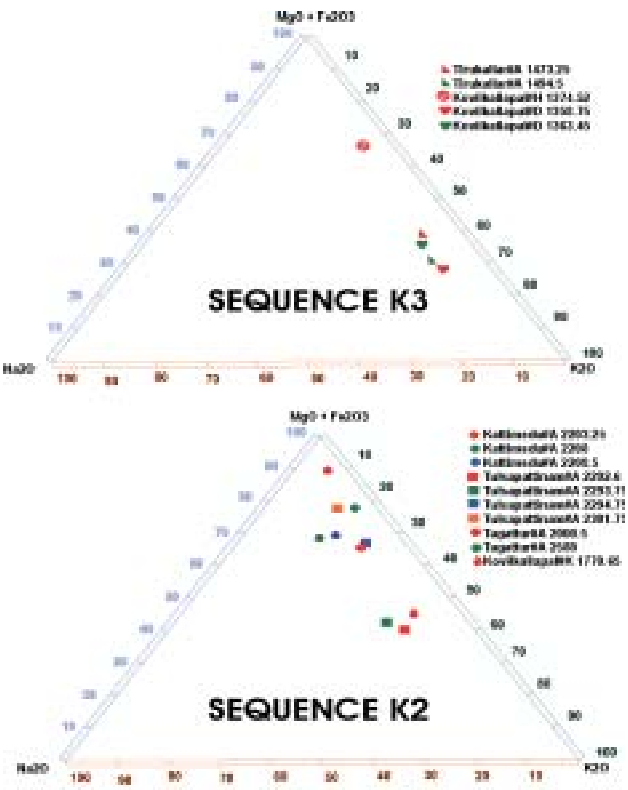


Fig. 7: Results of XRD studies of some selected wells

Fig. 8: Cores of a Kovilkalappal well pertaining to sequence K2

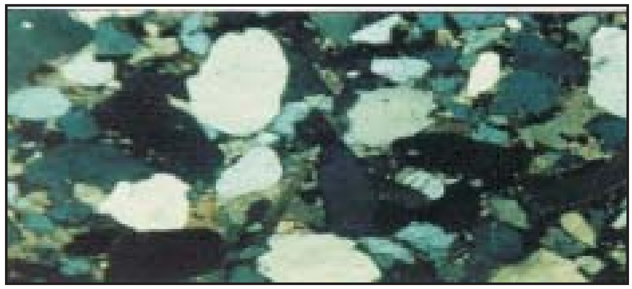


Fig. 9: Thin section of a core cut at a Tulsapattinam structure well in sequence K2 shows mixing of medium to well rounded grains with fine angular grains of quartz, feldspar and red algal grains in patchy sparite cement.

Sequence K3:

During starting of this time, the largely infilled extensional topography started subsiding slowly and evenly across the entire area, giving rise to an overall transgression and the accumulation of successions of relatively fine-grained, shallow marine strata. Thus the Initial part of the next sequence K3 (K3T) spanning Coniacian, Santonian and lower Campanian till 84 Ma was deposited in an overall transgressive low energy regime. Adjacent fault downthrown sides probably received some coarser grained sediments as slumps. Otherwise the overall lithology remained mostly argillaceous, the sequence set being the initial transgressive phase of 2nd order K3 sequence.

End of K3T (fig. 10) was triggered by fresh bout of tectonics and further reactivation of some pre existing faults, coinciding with a global major sea level fall. These newly formed and reactivated fault systems disturbed the pre-attained peneplained setup (at the end of sequence K1). A series of discrete, fault-bounded accommodation spaces formed and the rugged areas tried to attain peneplanation by fresh erosional activities in the highs and subsequent depositions in the lows as lowstand depositional systems (sequence K3R) spanning from mid Campanian to

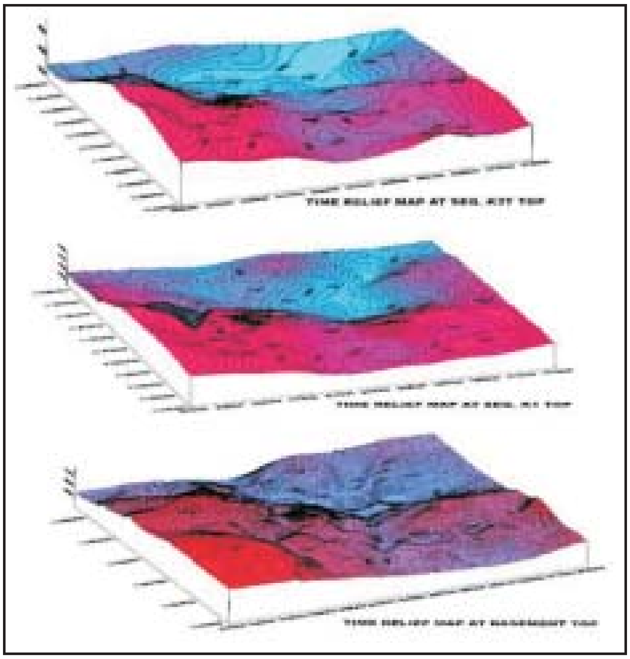


Fig. 10: Relief maps at the top of major unconformities

Maastrichtian. The studied cored intervals suggest stacked channel facies in shallow marine environments, which reworked earlier sediments.

However unlike sequence K2 in the southern segment of the study area, these channels were short in span and the depositions were always non linked accommodation space specific. The geochemical data indicating high content of K_2O also proves low mineralogical maturity of these sediments compared to the sediments of sequence K2 (Bhuvanagiri Formation). The lithostratigraphic equivalent of this sequence derived sands are Nannilam sands.

Deposition of this sequence seems to be continued undisturbed by any major tectonic episode. This phenomenon is proved by almost unchanged thickness of these sequences across the faults passing through them (fig.3-6), indicating enmass displacement. Thus attained peneplanation or near peneplanation was however a short lived one, being disturbed by fresh tectonics at the end of sequence K3, creating a major unconformity at the end (KTB).

Source rock

In general shales of the Cauvery basin are fair to good potential source rock. Shales within Andimadam Formation of lower Cretaceous age have proved to be effective source rock in North part of Nagapattinam sub basin. Wells drilled in South Nagapattinam sub basin have not encountered effective source rock facies. However potential sources are established in many wells in these areas.

The source rock development in the Kovilkalappal area is largely confined to the lows to the North of main Kovilkalappal high, with minimal development over the high. In the wells were studied in Kovilkalappal high only a thin sequence of potential source rock have been observed within Andimadam Formation.

However these studied source sediments in Kovilkalappal area are immature and incapable of generating hydrocarbon, probably due to shallow burial of sediments. The crude oil from Cretaceous reservoir (sequence K3R, Nannilam Formation) of Tulsapattinam is distinctly different from oil of Kovilkalappal and Tirukallar structures. Chemical properties of Tulsapattinam oil are indicative of non-marine source, while Kovilkalappal and Tirukallar oil have been sourced by organic matter of mixed type with a major contribution from marine organic matter. There is no source rock development in the sediments encountered at Tulsapattinam well upto last drilled depth. Neither source rocks have been developed in the wells drilled in adjacent structures namely Thriuturaipundi, Tagattur, Chokkanvur and Kariyapattinam. However these shales only makeup a minor percentage of the sequence K1 (Andimadam Formation) on the subbasin flanks, where the drilling was concentrated. It is assumed that the sequence K1 become more shaly towards the sub basinal depocentres.

The critical moment for Nagapattinam sub basin is 15 MY (Thomas et al, 2000).

Generation and migration

For detailed geochemical studies three synthetic locations have been selected in the study area. They are (fig.2) Location A: Near Tulsapattinam (approximate sediment thickness- 3150 m)

Location B: North of Thirutturaipundi (approximate sediment thickness- 3540 m) and

Location C: Near Umamaheswarapuram (approximate sediment thickness- 4800 m)

The location C is the deepest location in the study area with sediment column more than 4800 m.

Burial history and Maturity studies

Burial history diagram reveals that sediments attained 0.5% 0.7%, 1 %, 1.3%, and 2.0% VRo at depth1598m, 2489m, 3360m, 3779m and 4400m respectively in location C i.e. Umamaheswarapuram area (fig. 11). However, at locations B and A, where sediment base is at approximately 3540, 3150m respectively, sediments are yet to attain 1.32 % VRo. At location B sediments have attained 0.5%, 0.7%, 1% VRo at depth1860m, 2463m and 3324m respectively. At location A sediments have attained 0.5%, 0.7% at depth1596m, 2498m respectively. Sediment at depth 3262.2m and 3360m have expelled 20% of the generated hydrocarbons from location B and C respectively, whereas 20% of generated hydrocarbons are yet to be expelled from location A.

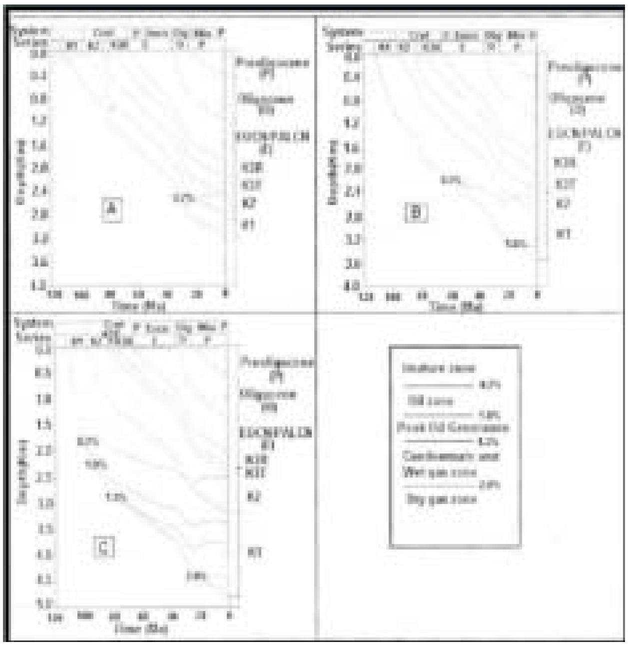


Fig. 11: Burial history and maturity window at synthetic locations A, B & C

Kerogen transformation

At present, kerogen transformations are 62%, 70%, 92% for sequence K1 (fig. 12) and 36%, 22%, 26% for sequence K2 (fig. 13) at location A, B, and C respectively. 50% kerogen transformation has taken place in the sequence K1 during 57mybp, 22mybp, 12mybp at location C, B, and A respectively.

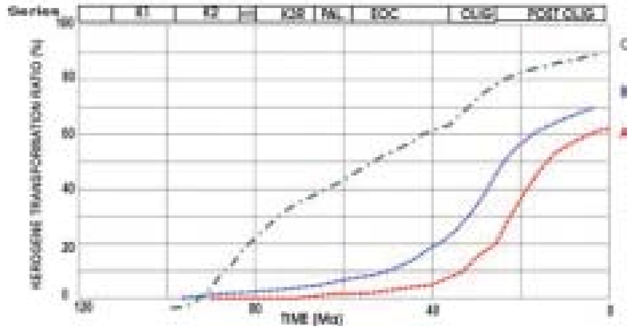


Fig. 12: Kerogen transformation for sequence K1

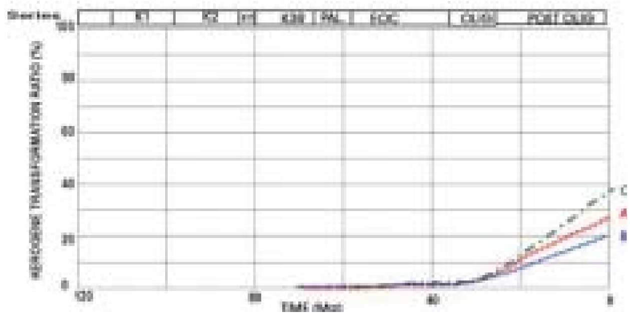
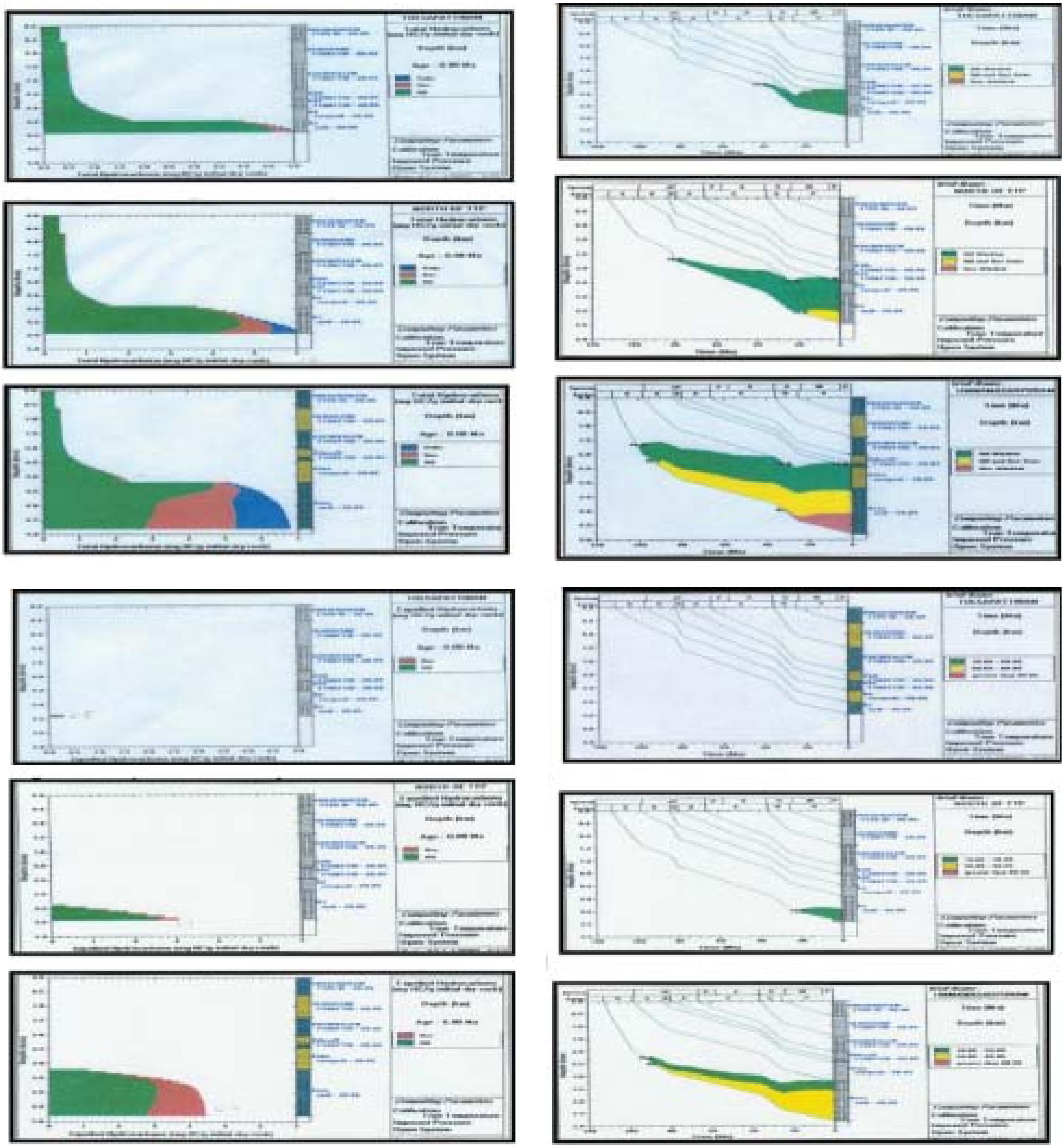


Fig. 13: Kerogen transformation for sequence K2

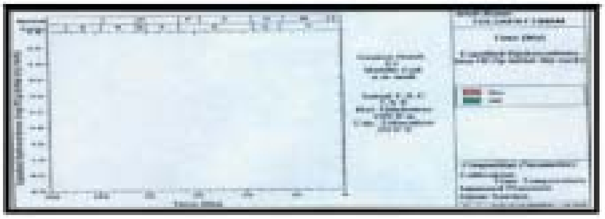
Hydrocarbon generated and expelled

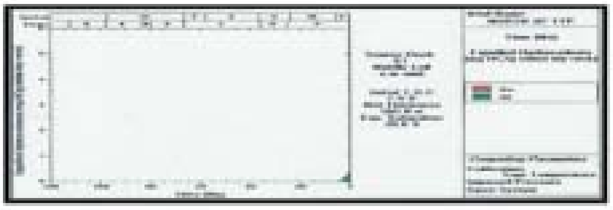
Up to 6.6, 6.0, and 5.0 mg hydrocarbon/g rock has been generated from location C, B, and A respectively (fig14). This generated amount includes oil, gas and coke. Up to 4.4, 3.1, 0.5 mg hydrocarbon/ g rock has been expelled from location C, B, and A respectively (fig. 15). This expelled amount includes oil and gas. Hydrocarbon expulsion threshold was assumed as volume of generated hydrocarbons filling 20% of the porosity. Hydrocarbon windows are within basal K3T to base of K1 and expulsion windows are within K1. Figure 16 shows hydrocarbon windows within basal K3T to base of K1 and Figures 17 shows expulsion windows within sequence K1 in wells at location A, B, and C respectively. Time and quantity of hydrocarbon expelled from Andimadam formation at location A, B, and C respectively are in Fig 18. Significant expulsion has taken place from sequence K1 at location C, but only minor to negligible expulsion appears to have occurred at location B. No expulsion seems to have taken place from Andimadam at location A.

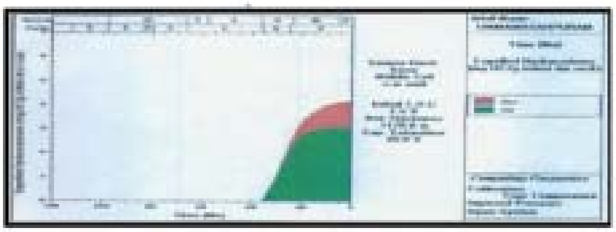


Discussion and conclusions

- In the south Nagapattinam area two major North – South trending Easterly hading normal extensional fault systems are identified. Extensional voids created by these faults were compensated by north-south trending westerly hading accommodation faults. Some of the structures created due to accommodation folding at the up thrown side of these faults have been probed for hydrocarbon (Kovilkalappal, Peruvalandan, Kattimedu, Killakadu etc.).







- Synrift sediments of Albian period (sequence K1: Andimadam Formation) deposited during early rift and rift climax period at deep basinal set up are the only effective source rocks, Umamaheswarapuram area being the most favourable locale.
- Late Rift clastics produced by comparatively low gradient drainage system and buried deeply in much of the graben can be a probable potential reservoir fairway in the region, provided they retain some favourable petrophysical characters.
- Early syndrift sequence K2 (Bhuvanagiri Formation) is mainly poorly sorted grains admixed with huge amount of clay matrix in the South. However in the Northern spread, well sorted submarine fan and channel fill deposits are identified for deliberate subtle trap exploration.
- Lowstand depositional systems within sequence K3R (Nannilam Formation) are evaluated to be an important target for exploration.

Acknowledgement

The authors express their thanks to ONGC for providing infrastructure and giving permission to publish the paper. Authors acknowledge the helps rendered by their peers and colleagues for the technical suggestions and helps rendered during this work. Special thanks are due to Shri S. Prabhakaran for allowing to use the selected plates and interpretations from his sedimentological studies.

The views expressed in this paper are that of the author(s) only and may not necessarily be of ONGC.